Innovative Technologies Could Improve Food Safety

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Gamma rays, electron beams, flash or steam pasteurization, steam vacuums, ozonation, ultra-high pressure treatment—these are some of the emerging technologies that U.S. food processors are investigating or implementing to help remove illness-causing pathogens in our food.

Many of these emerging food processing technologies are not new, but rather are innovative or expanded applications of existing technologies that had been examined, developed, or used for other purposes. For example, patents were awarded for the use of ionizing radiation to preserve food in 1905, but commercially, irradiation has been principally used to sterilize medical devices. Among disinfectants, ozone was initially used to cleanse drinking water in France in 1906 and has been used to treat bottled water in the United States since 1982. Processing food with high pressure was first examined in the United States during the late 1890's and early 1900's. However, in response to increased food safety concerns and heightened awareness of potential pathogen reduction abilities of these methods, recent advancements in many of these technologies have made them more commercially feasible in treating food.

The U.S. food processing industry in recent years has faced multiple challenges of expanding markets, increasing competition, and controlling known and newly emerging foodborne pathogens, all of which have raised concerns about the industry's ability to provide a larger, but consistently safe, food supply. Today's food processing system is vastly changed from that of the past where food was grown and sold locally. Many products now travel long distances between producer and consumer, with numerous processing points—from picking, boxing, shipping, to final preparation—separating farm and table.

Recognizing that food may be contaminated anywhere along the production chain, even on products thought to be pathogen-free, processors have realized that some form of intervention to disinfect food, perhaps at several steps, is necessary. But continued outbreaks of foodborne illnesses even after using conventional hot-water sprays, chlorine washes, and chemical treatments have led processors to examine new alternative technologies to help assure the safety of their products.

Government Regulations Boost Interest in New Technologies

Processors' interests in innovative food safety technology are driven partly by new government regulations for inspecting certain foods and controlling foodborne pathogens under the Hazard Analysis and Critical Control Points (HACCP) system. Processors of food covered by HACCP regulations are required to identify food safety hazards and indicate production steps where an intervention method can prevent or reduce these hazards. The HACCP regulations do not specify the intervention method to meet safety standards but rather places that decision with the processors, who may improve their existing processing methods or adopt a new technology, or combination of technologies, as part of their operating plan.

The HACCP system is quickly becoming a major tool in U.S. food safety efforts. HACCP was mandated for the U.S. seafood industry in 1995. The U.S. Department of Agriculture has since adopted the HACCP system for meat and poultry, which required the largest processors to have a HACCP plan in place by January 1998. All State and

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federally inspected meat and poultry slaughter and processing plants must implement HACCP by January 2000 (see "New Federal Policies and Programs for Food Safety" elsewhere in this issue).

In April 1998, the Food and Drug Administration (FDA) issued proposed rules that require the fruit and vegetable juice industry to use the HACCP system (see "New Juice Regulations Underway" elsewhere in this issue). In response to FDA's call for safer juice products, pasteurization of fruit and vegetable juices, including juice sold as fresh, has become an industry norm. On July 8, 1998, FDA published a rule requiring that unpasteurized fresh juice, which accounts for about 2 percent of all juice consumed in the United States, carry a warning label indicating that the product may contain harmful bacteria. If HACCP goes into effect for the juice industry, warning labels would no longer be needed. Many fresh juice producers, reluctant to place warning labels on their products for fear of losing sales, elected to pasteurize their products in response to the proposed HACCP regulations. Some apple juice and cider producers reported costs, based on size of the operation, ranging from $24,000 to $50,000 to upgrade their equipment to pasteurize their products.

Technologies Are Chosen Based on Benefits...

The greatest benefits to society from enhanced food safety are the reductions in the number of illnesses and deaths. But from an industry viewpoint, adopting a new food processing technology depends on the benefits for the processor versus the costs of the technology. An effective intervention method of killing dangerous foodborne bacteria, parasites, and viruses provides the most direct benefit to processors through production of a safer product, reducing risk of plant shutdowns, product recalls, and liability claims. An associated benefit of some technologies is the slowing of product spoilage, which extends the shelf-life of goods. Other benefits obtained from innovative technologies compared with existing treatment methods may include improved taste, appearance, and nutritional value of products.

...and Costs

Adopting new food safety treatments carries costs. For example, USDA's Food Safety and Inspection Service (FSIS) has estimated that initial "process modification costs" for all meat and poultry plants to comply with HACCP regulations could total between $5.5 million to $20 million. These cost estimates assumed that meat plants that did not comply with HACCP requirements would adopt steam vacuum systems and noncompliant poultry plants would implement antimicrobial rinses. Additional costs would be incurred by processors that implement innovative food safety methods. Expenses may include startup costs for equipment, operational redesign, buildings, and training, as well as variable operating costs for power, water, waste disposal, supplies, maintenance, and labor.

But limited information is available to industry decisionmakers on how to cost effectively control or reduce pathogens. A single new technology may greatly reduce specific pathogens at a cost comparable with, or less than, combinations of existing intervention methods. Other innovative technologies may affect multiple pathogens, or have a higher level of pathogen reduction, at costs higher than methods providing adequate control. Actual implementation costs are uncertain because some innovative technologies are only now starting in-plant operation, other approved methods are not yet fully embraced by industry, and still other methods are being tested onsite but lack formal approval from government regulatory agencies.

Effectiveness of Technologies Differs

Food safety technologies are based on thermal or nonthermal treatments to reduce foodborne pathogens. Thermal disinfectant technologies rely on heat, either dry or steam, to dehydrate or injure microorganisms. Heat, particularly through cooking, has long been the principal method of eliminating pathogens in food. New technologies, including steam pasteurization and steam vacuuming, continue to rely on heat to control or reduce harmful microorganisms in meat. Flash pasteurization is a rapid heating and cooling process to eliminate bacteria in fruit and vegetable juices. Nonthermal disinfectant technologies, such as chemical rinses, irradiation, ozonation, and ultra-high pressure, work without heat, affecting the composition and cellular activity of pathogens, ultimately killing them.

Which of the new food safety intervention methods are best? No single technology can be practically applied to all products and, within technologies, pathogen reduction varies among products treated. For example, a thermal intervention method may work for meat but not for heat-sensitive produce like lettuce. Where a water-based technology may effectively clean some produce, it may not be feasible for treating water-sensitive products like strawberries or raspberries. Within technologies, such factors as time of exposure, treatment temperature, and organic material levels or acidity of treatment water affect the effectiveness of intervention methods in reducing pathogens.

Thermal Technologies

Several large beef producers in the United States and Canada have adopted steam pasteurization systems, which gained USDA approval for use on beef in December 1995. These systems pass freshly slaughtered beef carcasses, already inspected, washed, and trimmed, through a chamber that exposes the beef to pressurized steam for approximately 6 to 8 seconds. The steam raises the surface temperature of the carcasses to 190-200 degrees Fahrenheit. The carcasses are then cooled with a cold-water spray. This process has proven successful in reducing pathogens, such as *E. coli* O157:H7, *Salmonella*, and *Listeria*, without use of any chemicals.

A steam pasteurization system installed in very large beef processing plants, handling up to 400 carcasses per hour, costs approximately $1 million, according to industry sources. Limited capacity systems, with a cost of $200,000 to $250,000, are also being developed for smaller beef processors and possibly for poultry and pork producers. Steam pasteurization systems have low operating costs as expenses include only those for power to generate steam and to dispose of the small amount of waste water.

Related to the steam pasteurization system are hand-held steam vacuums used to spot clean carcasses of fecal contamination. Steam vacuums, at a per unit cost of $13,000, employ simple technology and are widely used in the meat processing industry today. But the merger of steam and vacuum concepts has led to the development of a novel device to pasteurize the surface of raw meat. The device kills bacteria by first removing through a vacuum the air surrounding the meat, exposing the meat surface to steam at approximately 280 degrees Fahrenheit for less than 1/10 second, and finally re-evaporating through a cooling vacuum the steam condensation formed on the treated meat. The initial vacuum process removes air and water acting as an insulator on the product, which allows the steam to have direct contact on the meat, improving the effectiveness of the process and shortening the treatment time. The entire process takes less than one second to complete, thus no cooking of the product occurs. This vacuum/steam process is in the experimental stages, with USDA's Agricultural Research Service and industry jointly providing research.

Flash pasteurization is a high-temperature, short-time treatment in which pourable products, such as juices, are heated for 3-15 seconds to a temperature that destroys harmful microorganisms. The product is subsequently cooled and packaged. This aseptic processing reduces the thermal stress on the product and, consequently, is said to better maintain the product's nutrients and flavor. Most drink boxes and pouches use this pasteurization method as it allows extended, unrefrigerated storage while providing a safe product.

Nonthermal Technologies

The nonthermal food decontamination technology most generally known is irradiation. FDA approved irradiation's use on wheat and potatoes during the 1960's; spices, pork, fruits, and vegetables during the 1980's; poultry in the early 1990's; and, most recently, red meats (beef, veal, lamb) in December 1997. Commercially, however, irradiation has only been used in the United States to treat spices and seasonings found in processed foods, with limited additional application for fruits, vegetables, and poultry. Irradiation of red meat awaits final performance guidelines and standards from USDA (see "Food Irradiation—An Update" elsewhere in this issue). USDA issued proposed standards for public comment in February 1999.

Recent studies estimating the costs of foodborne illnesses have helped cultivate interest in irradiation technology. Widespread use of irradiation in the food processing industry, however, is hindered by some lingering doubts, among them concerns of consumer acceptance of irradiated food and economic considerations about processing food with existing commercial irradiation systems. Commercial irradiation technology, originally designed to sterilize medical devices through use of radioactive cobalt-60, is difficult to transfer to food processing. In treating food, the necessary exposure periods to cobalt-60 gamma radiation to achieve disinfection may increase product turnaround time and discolor food. Stand-alone irradiation plants located away from the processor are economically impractical in treating perishable food because of shipping time and costs. Traditional in-house gamma ray irradiators may be feasible only for large food processors because of high startup capital costs, which exceed $5.5 million. The seasonal nature of many agricultural products presents further concerns about irradiator "down time," leading to cost considerations regarding year-long monitoring of irradiators, continuous natural loss of radioactive material processing power, and licensed-operator training and retention.

To reduce the costs of irradiation, one company has designed a prefabricated unit that uses dry-stored cesium-137 as its power source. This design eliminates the space requirements of water pools needed to shield cobalt-60 systems. These cesium-137 units, some that require only 100 square feet of floor area, would be installed as part of the production process. The cesium units, like cobalt-60 irradiators, are intended to treat fully processed and packaged foods already stacked on pallets ready for shipping. The smallest cesium-137 irradiators cost approximately $1.5 million and, according to their manufacturer, can treat as little as 20 million pounds of product per year at an average cost of 2 cents per pound. Although irradiator "down time" issues remain, cesium-137 systems lose processing power at a much slower rate than cobalt-60 systems and some designs may reduce the time and expense for operator training. USDA's Agricultural Research Service and private industry have a cooperative research and development agreement to further test and evaluate a commercial-size cesium-137 irradiator that is scheduled to be installed at a USDA research facility in late 1999.

Electron beam technology, an alternative to gamma ray irradiation, uses high-energy electrons to penetrate products in their final shipping packaging, destroying harmful microorganisms within seconds. Run by standard electrical power, electron beam technology eliminates some concerns regarding system "down time" and continuous monitoring as the system is simply shut down by turning off the power. Pathogen reduction through electron beam technology is limited by the thickness and density of the treated product. For example, ground beef can be effectively treated at a depth of 4 inches in its final retail package. Electron beam capital costs are comparable with those for gamma irradiators, estimated at $5 million for a system designed to treat 100 million pounds of product per year. However, smaller, lower cost electron beam systems that are integrated directly into a food processing plant's production line are being developed.

Ozone, a form of oxygen that acts as a disinfecting agent, was deemed "generally recognized as safe" (GRAS) to treat food by an independent panel of scientists in July 1997. Ozone, long recognized as a disinfectant for municipal water supplies, has been used to treat most U.S. bottled water since the FDA affirmed ozone as GRAS for bottled water in 1982. Application of ozone as a disinfectant in other food products will require separate FDA approval. Ozone acts as a disinfectant in either its gaseous state or when dispersed in water. As a gas, ozone is an alternative cleansing agent for water-sensitive products, such as strawberries and raspberries, and was approved by USDA for the storage of meat in 1957. Research has shown that ozonated water is effective in reducing pathogens on surfaces of meat, poultry, and vegetables. Recapturing and reozonating wash water reduces water and discharge costs, particularly for high water users, such as poultry, fruit, and vegetable processors.

Capital costs of aqueous ozone systems vary, depending on size, ranging from $150,000 for a system appropriate for large poultry operations to $25,000 for small systems. Gaseous ozone systems for a large meat processor, for example, may cost $250,000, depending on the number of ozone generators needed. As with many emerging food safety technologies, commercial use of ozone systems to treat food is relatively unproven and, therefore, identification of best applications and general adoption of the technology has been slow.

Ultra-high pressure (UHP) technology has two applications in food processing—cutting food with UHP waterjets and destroying pathogens with hydrostatic pressure. UHP waterjets have been commercially used in the food processing industry for almost 20 years. The UHP waterjet is a USDA-approved method to cut and portion products, such as chicken, fish, and pizza. Waterjets eliminate the possibility of cross-contamination of products, if bacteria are present, that can occur with traditional cutting knives.

With recent advancements in ultra-high pressure engineering, commercial interest in reducing foodborne pathogens by exposure to hydrostatic pressure has increased. Although USDA scientists initially documented the use of pressure to preserve milk, fruits, and vegetables as early as 1899, the first UHP-treated foods were commercially introduced in Japan in the 1990's. In the United States, automated UHP equipment is being developed for commercial application to treat pourable products, such as juices, dressings, soups, and salsa. Research has shown that exposure to UHP for 30 seconds to 2 minutes destroys foodborne pathogens and microbes that spoil food but does not affect flavor, appearance, or nutritional value. Processing food with pressure is more expensive than traditional heat pasteurization because of high capital costs of UHP equipment, adding approximately 10-50 cents per gallon of product according to industry sources.

Industry Faces Choices and Unknown Costs

Each emerging food processing technology has its advantages and disadvantages, and research continues on which decontamination processes, or combination of methods, provide maximum benefits for specific products. In addition to improving food safety, adoption of pathogen reduction methods by food processors depends on developing safeguards to ensure worker safety and satisfying regulatory and environmental constraints. These concerns add to the complexity in deciding which technology to use.

Technical feasibility and regulatory approval do not guarantee that food processors will adopt a technology. Each emerging technology must also show that it cost effectively reduces or controls pathogens compared with competing treatments, thereby providing a market advantage to the food processor, before commercial adoption. Even then, commercial use of an expensive, new technology may be limited to large food processors who can afford to buy or lease innovative treatment systems. A remaining concern—consumer acceptance—is a final obstacle before industry implements a little known food processing technology.

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